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United States Patent [19]

Collins, Jr.

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[54] ROTARY DEVICE FOR REMOVING PARTICULATES FROM A GAS STREAM

[75] Inventor: Earl R. Collins, Jr., La Canada, Calif.

[73] Assignee: California Institute of Technology, Pasadena, Calif.

[21] Appl. No.: 667,712

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[51] Int. Cl.[5] B03C 1/00

[52] U.S. Cl. 55/6; 55/127; 55/152

[58] Field of Search 55/127, 152, 6

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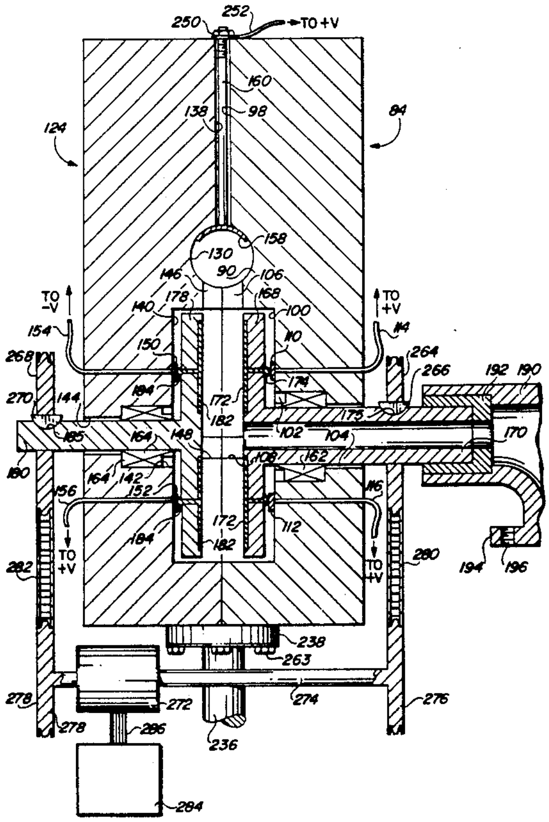
Primary Examiner—Bernard Nozick
Attorney, Agent, or Firm—John J. Posta, Jr.

[57] ABSTRACT

A rotary particulate separator for removing particulates from a pressurized gas stream such as that emanating from a reactor vessel is disclosed which precharges the particles in the gas stream, and then utilizes the charge on the particles to induce them from the main flow path through an airblock and into the rotary particulate separator. The rotor of the rotary particulate separator has polarized plates which use a first charge opposite that on the charged particles to attract the particles as they enter the rotation chamber, and then use a second charge of the same polarity as the charge on the charged particles to release the particles into a control gas flow vortex which draws the particles radially inwardly into an exit aperture contained in the center of one of the rotor segments and out from the device. Pressure letdown devices are used to drop the pressure of both the control gas flow exiting the separator with the particles and the cleaned gas stream.

28 Claims, 6 Drawing Sheets



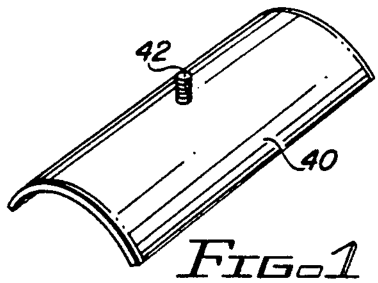


FIG. 1

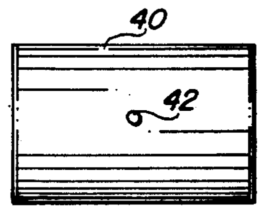


FIG. 2

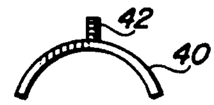


FIG. 3

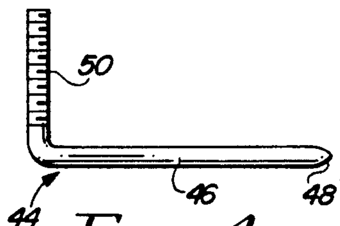


FIG. 4

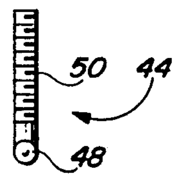
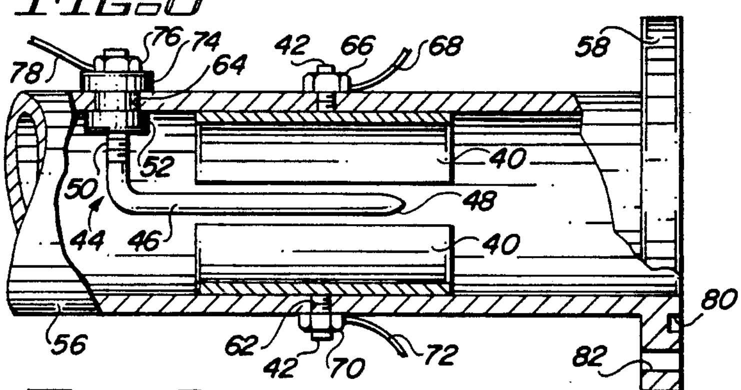


FIG. 5

FIG. 6

FIG. 7

FIG. 8



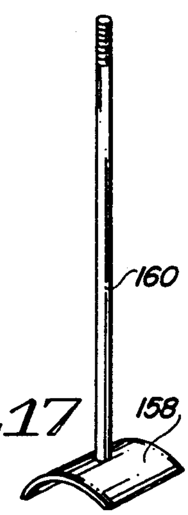
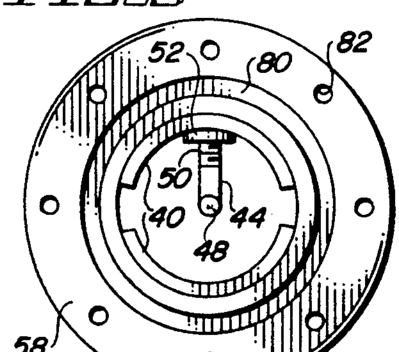


FIG. 17

FIG. 9



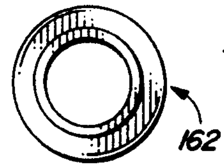


FIG. 19

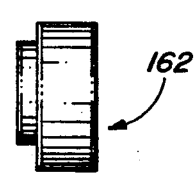
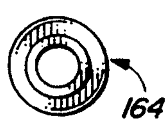


FIG. 20

FIG. 18



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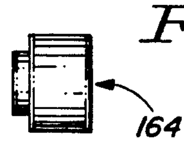


FIG. 22

FIG. 10

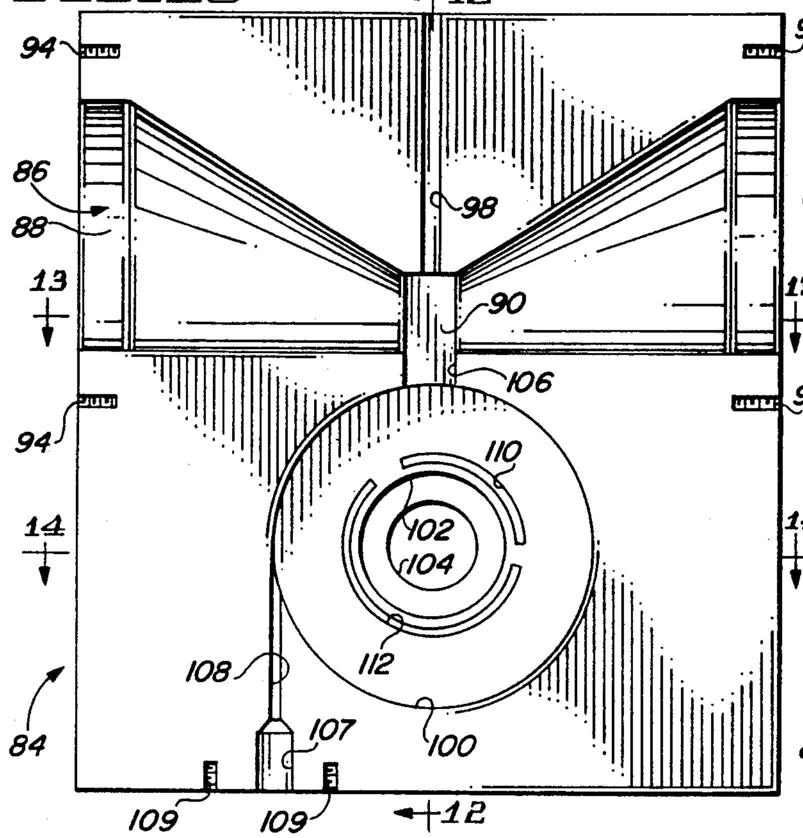
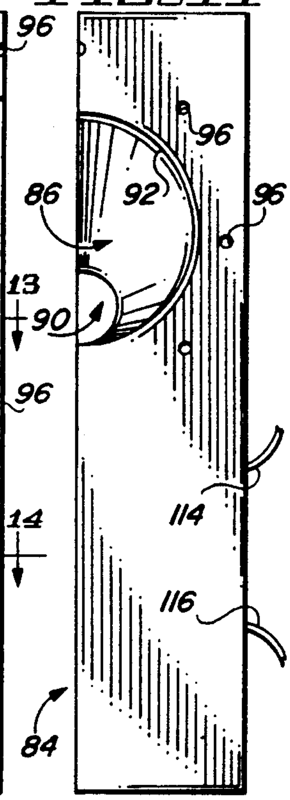
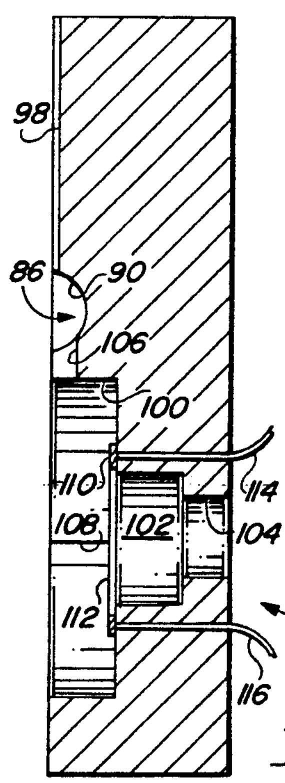


FIG. 11





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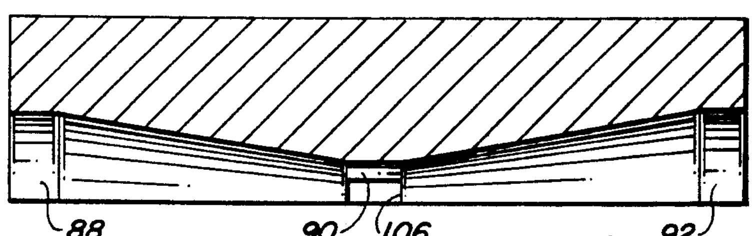

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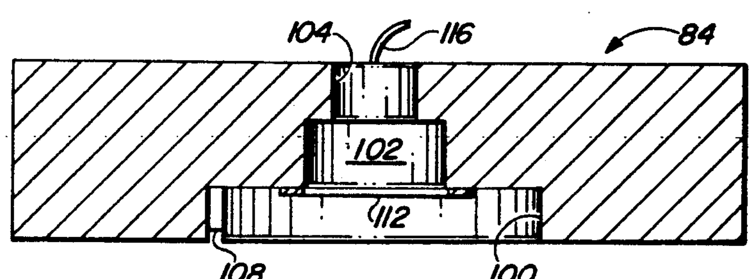

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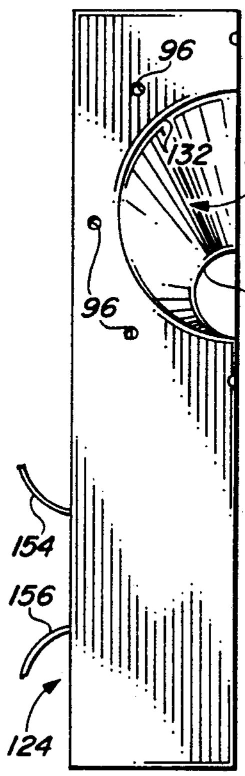


FIG. 16

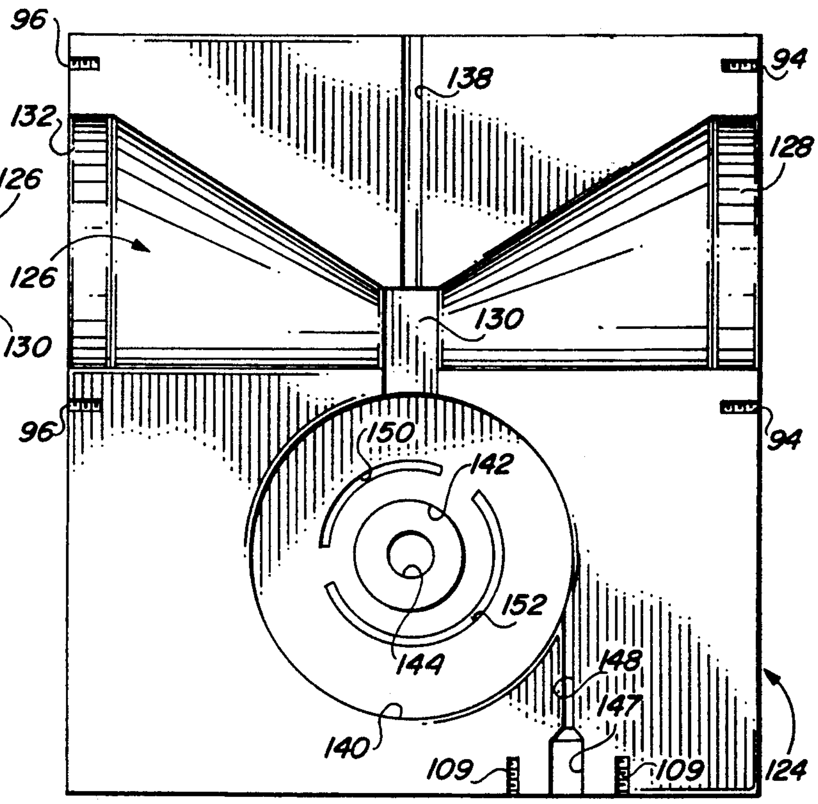


FIG. 15

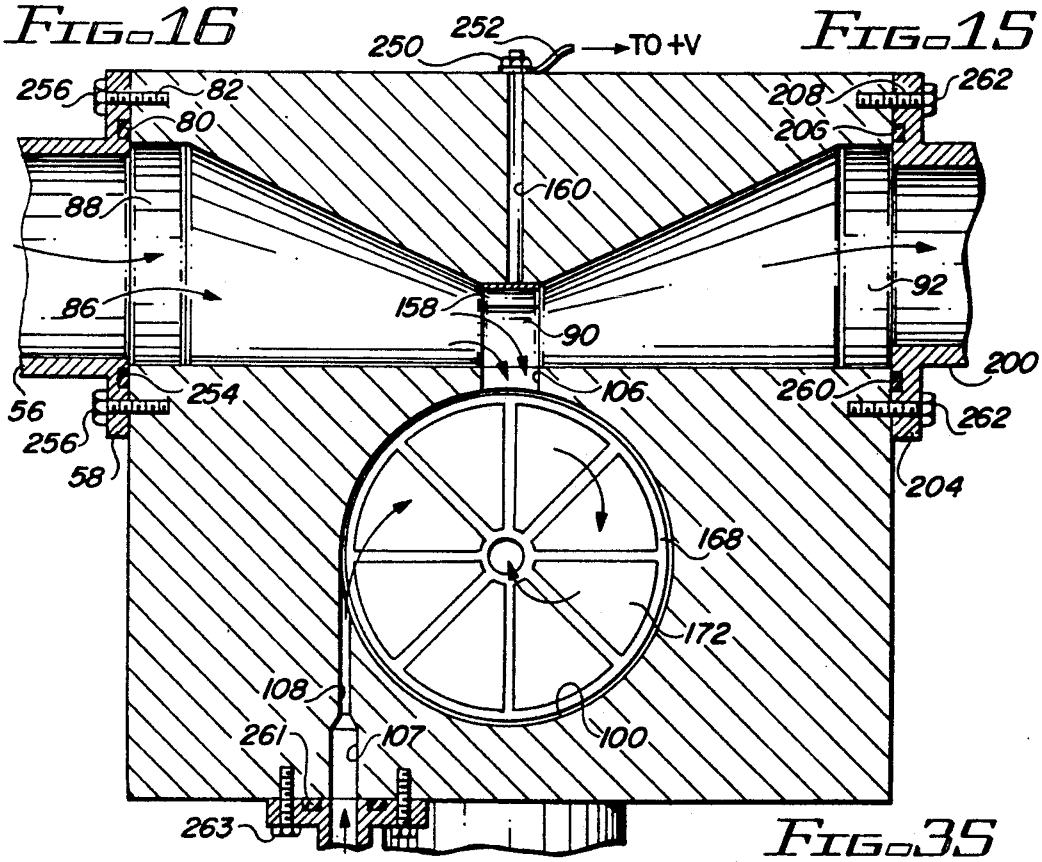


FIG. 35

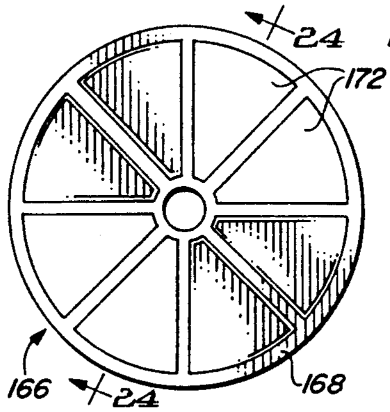


FIG. 23

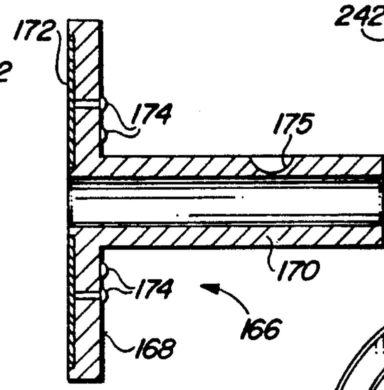


FIG. 24

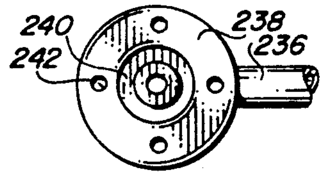
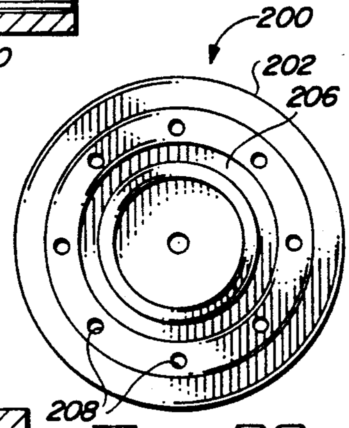


FIG. 32



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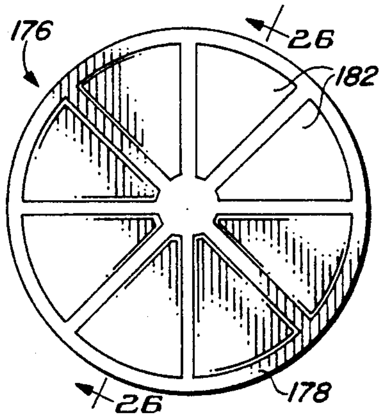


FIG. 25

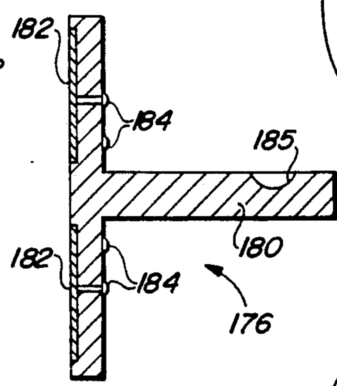


FIG. 26

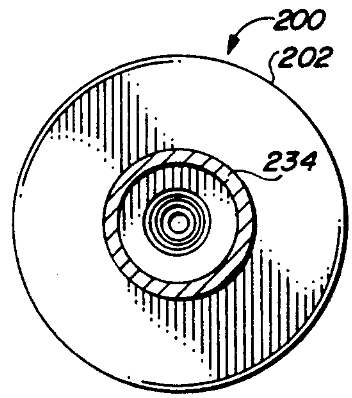


FIG. 30

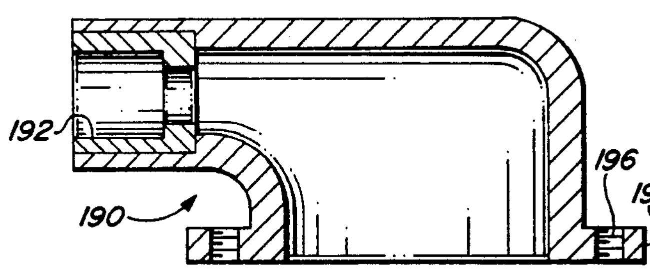


FIG. 27

FIG. 28

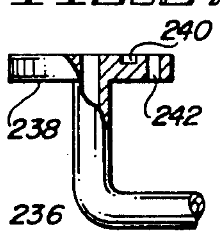
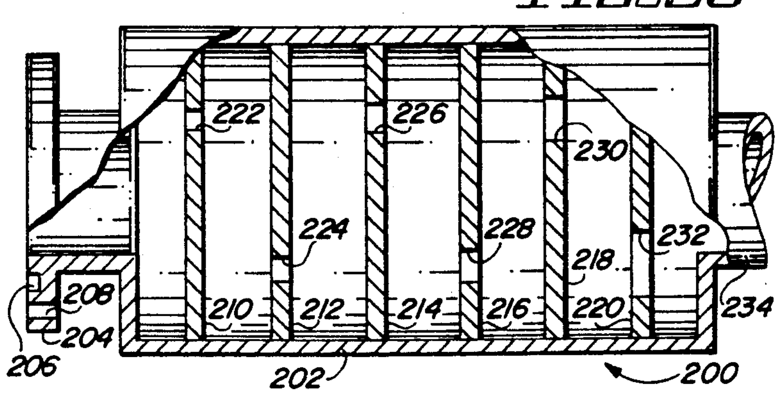
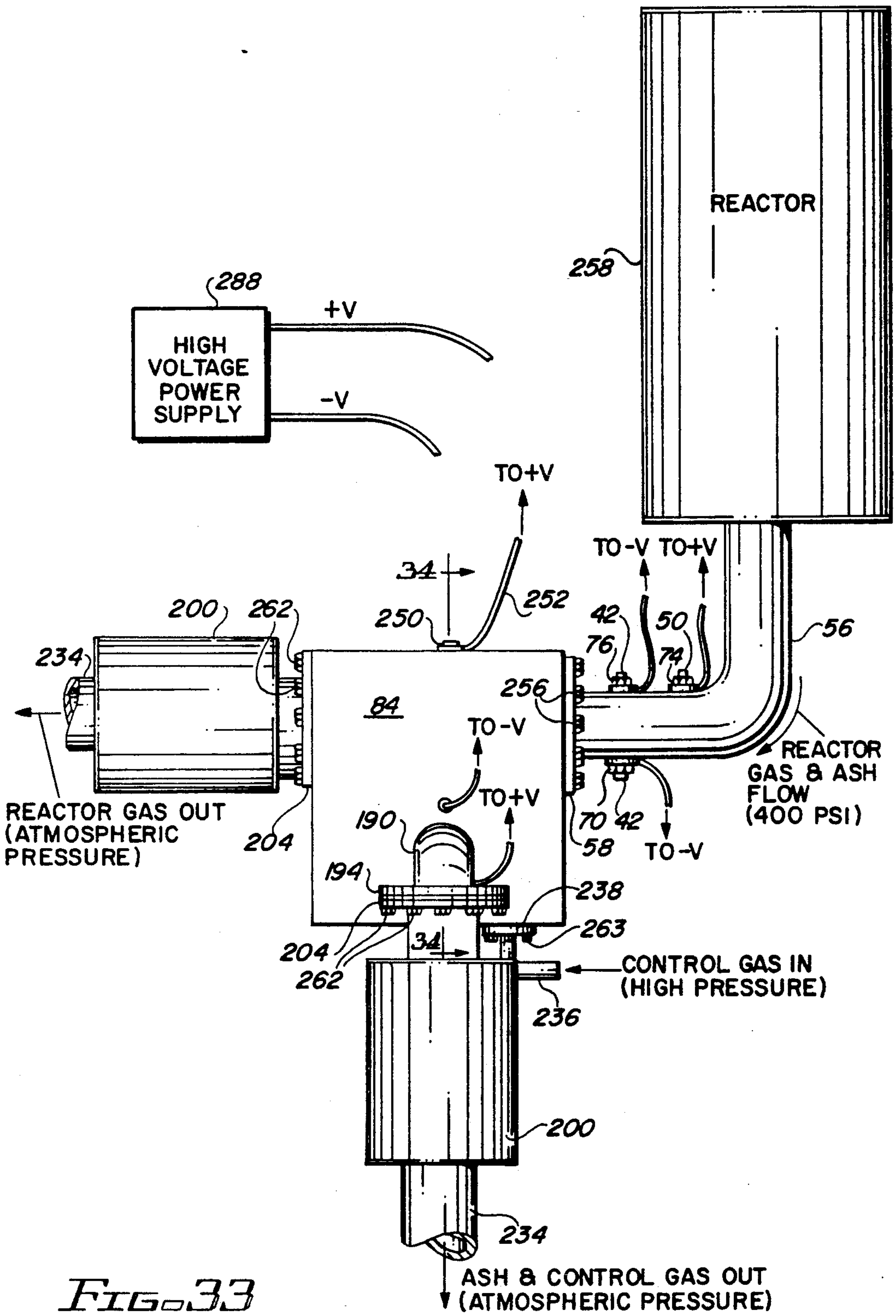
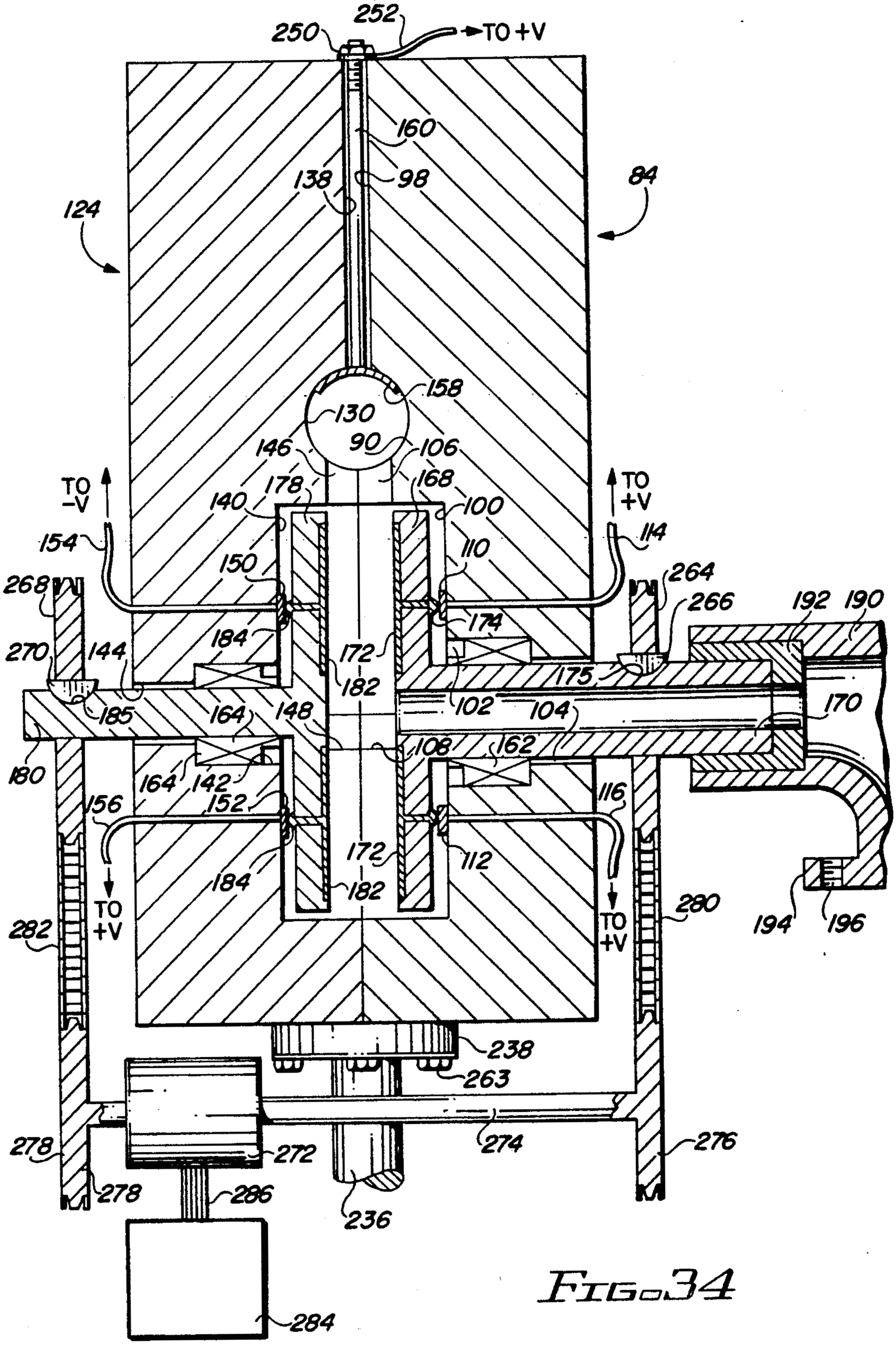


FIG. 31




REACTOR
258
288
HIGH VOLTAGE POWER SUPPLY
+V
-V
TO+V
34
250
252
TO-V TO+V
42
50
56
200
262
234
76
74
256
84
TO-V
REACTOR GAS & ASH FLOW (400 PSI)
TO+V
REACTOR GAS OUT (ATMOSPHERIC PRESSURE)
204
190
70 42
58
TO-V
194
238
263
204
262
34
CONTROL GAS IN (HIGH PRESSURE)
236
200
234
ASH & CONTROL GAS OUT (ATMOSPHERIC PRESSURE)
FIG. 33



250
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TO +V
160
138
98
124
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TO -V
TO +V
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FIG. 34

ROTARY DEVICE FOR REMOVING PARTICULATES FROM A GAS STREAM

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA Contract, and is subject to the provisions of Public Law 96-517 (35 U.S.C. 202) in which the Contractor has elected to retain title.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to a rotary particulate separator for removing particulates from a pressurized gas stream such as that emanating from a reactor vessel, and more particularly to a particulate separator which utilizes a charge placed on particles in the gas stream first to induce them from the main flow path into a vortex generator, and then to carry the charged particles with a rotor located in the vortex generator into a vortex generated by a control gas flow which draws the particles radially inwardly into an exit aperture and out from the device.

2. Description of Background Information

A wide variety of devices either utilize gas as a working fluid to remove particulates from an operating environment or produce a gaseous stream containing particulates which are released by an operating environment. In either case, a gas stream is produced by a multitude of different systems, and that gas stream must be cleaned to remove the particulates prior to discharging the gas stream into the environment. One particular example of such an operating environment which presents particular problems is that of a reactor vessel producing a high pressure gas stream containing particulates which must be removed and collected for proper disposal.

As might be expected, the art is replete with examples of devices for removing particulates from a gas stream. Most of the early particulate separators are mechanical filters having a barrier construction which allows gas to flow therethrough. Such mechanical filters are quite effective in removing particulates having a sufficiently large physical size so as to enable the mechanical filter to trap the particulates. However, in many systems in use today, including the reactor environment contemplated herein, particulates produced are too fine to become trapped in a mechanical filter unless the filter is sufficiently small, in which case the particulates tend to quickly clog the filter.

Particulates in the reactor environment contemplated herein have a typical diameter of approximately two to five microns, with the gas stream having a typical pressure of 300 to 400 PSI. The particulates must be removed from the high pressure gas stream, which emanates from the reactor vessel on a continuous basis, thereby necessitating continuous processing rather than batch processing. Given the particulate size of two to five microns, the settling rate is from 0.7 to 4.4 inches per second, as per Stoke's law.

A vast number of references exist which utilize various types of electrostatic precipitation. The simplest of these devices is the basic electrostatic precipitator which places a charge on particulates, and uses electrostatic force to collect them at a collection location in the device. Examples of such devices are found in

U.S. Pat. No. 3,400,513, to Boll, in U.S. Pat. No. 3,820,306, to Vincent, and in U.S. Pat. No. 4,544,382, to Taillet et al.

The Boll patent has a gas stream ducted into and out of a housing, with particulates in the gas stream being charged upon entering the housing and collected by a precipitator. The Vincent device is made of a plurality of charged plates with dielectric plates (or grids) therebetween, with the dielectric plates receiving induced potentials and causing precipitation of particles. The Taillet et al. patent uses ion generators to produce space charges in an enclosure in which the gas stream containing particulates flows, thus initiating precipitation of the particulates.

The next step in increasing complexity of electrostatic precipitators involves the addition of a filter element to entrap particles drawn into the filter element by electrostatic force. Devices utilizing this type of construction are illustrated in U.S. Pat. No. 4,339,782, to Yu et al., in U.S. Pat. No. 4,501,598, to Long, and in U.S. Pat. No. 4,871,515, to Reichle et al.

The Yu et al. patent illustrates an ionizer utilized to charge particulates in a gas stream, with a charged filter element being used to electrostatically attract and contain particulates in the gas stream. The Long reference uses a filter element disposed in the gas flow, with portions of the filter medium fluttering to generate electrostatic charges to attract and remove particulates from the gas stream. The Reichle et al. patent uses a filter element containing "windshadow areas," which shield trapped particles from the gas stream to prevent them from reentering the gas stream once trapped in the filter by electrostatic separation.

An enhancement to electrostatic separation using a fixed filter is illustrated in U.S. Pat. No. 3,783,588, to Hudis, and in U.S. Pat. No. 4,229,187, to Stockford et al. In the Hudis patent, moving sheets of filter material are passed through a gas stream, with electrostatic charge being used to attract particulates to the sheets. The sheets may be cleaned when they are not contained in the gas stream. The Stockford et al. reference teaches the use of a filter media which develops an electrostatic charge in a dry, fast gas stream.

A more complex type of electrostatic precipitator is taught in U.S. Pat. No. 4,093,430, to Schwab et al., and in U.S. Pat. No. 4,846,430, to Burger et al. These devices charge particles in the gas stream and remove them in a wet process known as "scrubbing." The Schwab et al. reference uses a dense electrostatic field to charge particulates which may then be removed by a scrubber. The Burger et al. patent teaches dispersing scrubbing liquid into the gas stream and then ionizing the particulates and liquid droplets, which are removed by a high speed brush charged to attract the particulates and the droplets.

These devices discussed briefly above are all useful in their preferred environments, but are not acceptable for use with the reactor to remove the contaminated particulates in the high pressure gas stream leaving the reactor vessel. The high pressure, continuous flow characteristics of the reactor combined with the necessity for complete removal of the particulates present a situation the devices discussed above are not able to cope with in an acceptable manner.

To date, the only devices which have been even close to acceptable in particulate removal characteristics are centrifugal type devices rather than electrostatic filters. Even these devices have not been completely successful. Looking once again at the art for further variations, two additional references have been located, both of which combine centrifugal force with electrostatic attraction of particulates. These devices are illustrated in U.S. Pat. No. 4,134,744, to Peterson et al., and in U.S. Pat. No. 4,398,928, to Kunsagi.

The Peterson et al. device is designed for an industrial application, and has a disk with plural pie-shaped segments through which the gas stream is directed. Alternating segments of the disk are charged with opposite polarities, and dielectric fluid is supplied to the center of the disk. The disk is spun to flow the dielectric fluid radially outwardly, and the charges on the segments of the disk attract particulates in the gas stream. The dielectric fluid thus washes particulates attracted to the disk outwardly, where the charge is neutralized and the fluid, together with the particulates, is collected.

While the Peterson et al. device represents an interesting approach, it simply is not suitable for the high pressure reactor application contemplated herein. The particulates in the gas stream are not precharged, and since they are very small, they may well flow through the disk and not be removed. In addition, the use of the dielectric fluid creates an additional waste disposal problem, exacerbating the situation instead of improving it.

Finally, the Kunsagi reference teaches a centrifugal separator using a nozzle directed tangentially to impart a high rotational velocity to the gas stream in a chamber. Electrical charges carried on aerosol charge carriers are used to charge small particles, which are then attracted to the outer walls, where they are carried away by the scavenging flow of the larger particles. The Kunsagi reference is designed for removal of particulates generated in combustion of coal, which are much larger than the particulates of the application contemplated herein. Thus, none of these references suggest a device or method for accomplishing the removal of particulates from a reactor gas stream in a suitable manner.

It is accordingly the primary objective of the present invention that it operate to remove substantially all of the particulates contained in the gas stream emanating from a reactor vessel. Thus, the particulate separator of the present invention must be operable on a continuous, high pressure gas stream including particulates to remove the particulates as efficiently as possible. The particulate separator must also be operable on the small particulates typically contained in a reactor vessel gas stream, which range from approximately two to five microns, and which have small settling rates.

It is a further objective of the present invention that it operate in a manner not requiring a scrubbing fluid, the use of which would further exacerbate the problem of substance disposal. In addition, the solution to the problems enumerated above should not involve the use of a filter medium, which may become clogged or which may require periodic maintenance or changing. It is an additional objective of the present invention that it operate to effectively separate the gas in the gas stream from particulates contained therein while using as little gas as possible.

It is a still further objective of the present invention that it be relatively compact and inexpensive, both to construct, as well as to operate and maintain. The particulate separator of the present invention should also enable the conversion of the high pressure gas stream containing particulates to a low pressure outlet flow of gas at a first output point, and a low pressure outflow of particulates and a small amount of gas at a second output point. Finally, it is also an objective that all of the aforesaid advantages and objectives be achieved without incurring any substantial relative disadvantage.

SUMMARY OF THE INVENTION

The disadvantages and limitations of the background art discussed above are overcome by the present invention. With this invention, a particulate separator is disclosed which will separate even very small particles from a high pressure, continuous flow gas stream with a high degree of efficiency. As such, the particulate separator of the present invention is suitable for use with a reactor vessel to separate the particulates contained in the gas stream exhausted from the reactor.

The particulate separator of the present invention uses electrostatic principles at two different points in the separation operation. Prior to arriving at either of these two points, the particulates in the gas stream are electrostatically charged as they pass through a plasma zone in the flow path from the reactor vessel. In the preferred embodiment, the particulates are all charged with a positive charge.

The flow path following the charging apparatus includes a particulate removal tube which has a cross-sectional area which smoothly varies from a larger cross-sectional area on the inlet end, to a smaller cross-sectional area in the central portion thereof, and back to a larger cross-sectional area on the outlet end. At the location of the smallest cross-sectional area in the central portion of the particulate removal tube, there is an aperture opening downwardly into a vortex generator. On the top side of the smallest cross-sectional area in the central portion of the particulate removal tube opposite the aperture leading to the vortex generator is a repelling plate which is charged with the same polarity as the charge on the particulates (a positive charge in the preferred embodiment).

The charge on the repelling plate forces the charged particulates away from the repelling plate as they pass through the smallest cross-sectional area in the central portion of the particulate removal tube. The charged particulates are thus forced through the aperture in the bottom of the smallest cross-sectional area in the central portion of the particulate removal tube into the vortex generator. The gas stream continues to flow through the particulate removal tube toward the outlet end thereof, with the particulates removed. The cleaned gas stream then leaves the particulate removal tube, and flows through a pressure letdown device, at the outlet of which the cleaned gas stream exits at atmospheric pressure.

The vortex generator comprises a cylindrical chamber which is closed on both ends, with the aperture through which the particulates enter the vortex generator being on the side of the cylindrical chamber approximately midway between the two ends and at the top thereof. This top position will be referred to as the twelve o'clock position. A control gas is supplied tangentially to the vortex generator from the side of the cylindrical chamber at nine o'clock, and flows clockwise in the cylindrical chamber.

Two rotating disks are located in the vortex generator parallel to and adjacent the ends of the cylindrical chamber. The area between the two rotating disks, which rotate clockwise, includes the area into which the particulates and the control gas flow. As the center of one of the disks is an aperture through which particulates and control gas may leave the vortex generator. Thus, it will be appreciated by those skilled in the art that a vortex will be created by the tangential infusion of the control gas which exits at the center of one of the disks. The vortex will act to remove the particulates forced into the vortex generator.

The present invention at this point uses the charge on the particulates for a second time. The rotating disks have a plurality of spaced-apart, pie-shaped conductive segments on their facing sides. When the conductive segments are oriented from approximately 12 o'clock to four o'clock, the conductive segments on the disks are charged (negatively, in the preferred embodiment) to attract the charged particulates. Thus, the charged particulates will rotate with the conductive segments on the disks from the 12 o'clock position to the 4 o'clock position.

When the conductive segments on the disks reach the 4 o'clock position, the conductive segments on the disks are charged (positively, in the preferred embodiment) to repel the charged particulates. The charged particulates will move off of the conductive segments on the disk, and, caught up in the vortex created by the control gas, will exit the vortex generator through the aperture in the disk. The control gas stream and the particulates then flow through a pressure letdown device, at the outlet of which the control & gas and particulates exit at atmospheric pressure.

It may therefore be seen that the present invention teaches a device which operates to remove substantially all of the particulates contained in the gas stream emanating from a reactor vessel. The particulate separator of the present invention is operable on a continuous, high pressure gas stream which includes particulates to process the gas stream to remove the particulates as efficiently as is possible. The particulate separator will operate to remove the small particulates typically contained in a reactor vessel gas stream, despite the fact that & they range from approximately two to five microns, and thereby have small settling rates.

The particulate removal system of the present invention operates in a manner not requiring a scrubbing fluid, therefore not further exacerbating the problem of substance disposal. In addition, the present invention does not involve the use of a filter medium and its attendant problems of clogging or requiring periodic maintenance or changing. The present invention also effectively separates the gas in the gas stream from particulates contained therein while using as little gas in the particulate waste stream as is possible.

In addition, the particulate separator of the present invention is relatively compact and inexpensive, both to construct, and also to operate and maintain. The particulate separator of the present invention enables the conversion of the high pressure gas stream containing particulates into a low pressure outlet flow of gas at a first output point, and a low pressure outflow of particulates and a small amount of gas at a second output point. Finally, all of the aforesaid advantages and objectives are achieved without incurring any substantial relative disadvantage.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other advantages of the present invention are best understood with reference to the drawings, in which:

FIG. **1** is an isometric view of a curved electrode plate;

FIG. **2** is a top plan view of the curved electrode plate shown in FIG. **1**;

FIG. **3** is an end view of the curved electrode plate shown in FIGS. **1** and **2**;

FIG. **4** is a side view of an L-shaped electrode;

FIG. **5** is a downstream view of the L-shaped electrode shown in FIG. **4**;

FIG. **6** is a side view of an insulated, threaded insert for use in mounting the L-shaped electrode shown in FIGS. **4** and **5**;

FIG. **7** is a top view of the insert shown in FIG. **6**;

FIG. **8** is a partially cut away side view of a segment of tubing in which two of the curved electrode plates shown in FIGS. **1** through **3** .are mounted on opposite sides, and in which the L-shaped electrode shown in FIGS. **4** and **5** is mounted using the insert shown in FIGS. **6** and **7** with the long leg of the L-shaped electrode disposed between the curved electrode plates;

FIG. **9** is an end view of the segment of tubing shown in FIG. **8** from the downstream end, showing the flange mounted thereon;

FIG. **10** is a plan view of the interior side of a first housing half defining half of the particulate removal tube and half of the cylindrical chamber defining the vortex generator, showing the narrowed central portion of the particulate removal tube, the bearing receiving aperture and the shaft aperture in the cylindrical chamber, the split ring commutator for charging conductive segments on the disk of a rotor, and half of the control gas inlet passageway;

FIG. **11** is an end view of the first housing half shown in FIG. **10** showing the outlet end of the particulate removal tube and the wires

leading to the split ring commutator;

FIG. **12** is a first cross-sectional view of the first housing half shown in FIGS. **10** and **11** showing the aperture between the smallest cross-sectional area in the central portion of the particulate removal tube and the cylindrical chamber forming the vortex generator;

FIG. **13** is a second cross-sectional view of the first housing half shown in FIGS. **10** through **12** also showing the aperture between the smallest cross-sectional area in the central portion of the particulate removal tube and the cylindrical chamber forming the vortex generator;

FIG. **14** is a third cross-sectional view of the first housing half shown in FIGS. **10** through **13** showing the bearing receiving aperture and the shaft aperture in the cylindrical chamber, and half of the control gas inlet passageway;

FIG. **15** is a plan view of the interior side of a second housing half defining half of the particulate removal tube and half of the cylindrical chamber defining the vortex generator, showing the narrowed central portion of the particulate removal tube, the bearing receiving aperture and the shaft aperture in the cylindrical chamber, the split ring commutator for charging conductive segments on the disk of a rotor, and half of the control gas inlet passageway;

FIG. **16** is an end view of the second housing half shown in FIG. **15** showing the outlet end of the particulate removal tube and the wires leading to the split ring commutator;

FIG. **17** is an isometric view of a curved electrode plate for mounting in the smallest cross-sectional area in the central portion of the particulate removal tube

(FIG. 10 and 15) opposite the aperture between the smallest cross-sectional area in the central portion of the particulate removal tube and the cylindrical chamber forming the vortex generator;

FIG. 18 is an end view of the curved electrode plate shown in FIG. 17;

FIG. 19 is a plan view of a bearing and seal for mounting in the bearing aperture in the first housing half shown in FIG. 10;

FIG. 20 is a side view of the bearing and seal shown in FIG. 19;

FIG. 21 is a plan view of a bearing and seal for mounting in the bearing aperture in the second housing half shown in FIG. 15;

FIG. 22 is a side view of the bearing and seal shown in FIG. 21;

FIG. 23 is a plan view of the disk of a first rotor for mounting in the first housing half shown in FIG. 10 using the bearing and seal shown in FIGS. 19 and 20;

FIG. 24 is a cross-sectional view of the first rotor shown in FIG. 23;

FIG. 25 is a plan view of the disk of a second rotor for mounting in the second housing half shown in FIG. 15 using the bearing and seal shown in FIGS. 21 and 22;

FIG. 26 is a cross-sectional view of the second rotor shown in FIG. 25;

FIG. 27 is a cross-sectional view of an L-shaped connector tube having at one end thereof a seal therein for rotatably receiving the shaft of the first rotor shown in FIGS. 23 and 24, and having a flange disposed at the other end thereof;

FIG. 28 is a cutaway view of a pressure letdown device having disposed therein a plurality of plates with apertures in them;

FIG. 29 is an end view of the pressure letdown device shown in FIG. 28 from the inlet end, showing a flange mounted thereon;

FIG. 30 is an end view of the pressure letdown device shown in FIGS. 28 and 29 from the outlet end, showing the apertures in the plates located therein;

FIG. 31 is a partially cutaway side view of a control gas supply tube;

FIG. 32 is a top plan view of the control gas supply tube of FIG. 31 showing a flange located thereon;

FIG. 33 is a side view of the particulate separator system of the present invention showing a reactor vessel, a high voltage power supply, and the relative location of the various components shown in the figures described above;

FIG. 34 is a sectional view of the assembled housing of the particulate separator of the present invention showing the gear drive used to turn the disks of the first and second rotors; and

FIG. 35 is a sectional view of the assembled first housing of the particulate separator of the present invention showing the flow path of particulates, the flow path of the control gas, and the rotation of the disk of the first rotor.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The preferred embodiment charges particulates to utilize electrostatic principles in the separation of the particulates from a gas stream. The various components used to accomplish the charging of particulates carried in the gas stream from a reactor vessel, or from another source of contaminated gas, are shown in FIGS. 1 through 9. Referring first to FIGS. 1 through 3, a curved electrode plate 40 is illustrated which will be used as one electrode to charge the particulates in the gas stream. The curved electrode plate 40 is curved to fit on the inner diameter of a segment of tubing (not shown) Which, in the preferred embodiment, will have an inner diameter of approximately one to two inches. The exact size of the tubing to be used will depend on the characteristics of the gas stream and the particulates in the gas stream.

The curved electrode plate 40 has a threaded stud 42 mounted in a central position on the convex side thereof, with the threaded stud 42 being orthogonal to a plane tangent to the convex side of the curved electrode plate 40. The threaded stud 42 may be soldered to the curved electrode plate 40. The curved electrode plate 40 and the threaded stud 42 are both made of conductive material.

Referring now to FIGS. 4 and 5, an L-shaped electrode 44 is illustrated which will be used as the other electrode to charge the particulates in the gas stream. The L-shaped electrode 44 has a long leg 46 terminating in a pointed tip 48. The shorter leg 50 of the L-shaped electrode 44 is threaded to facilitate mounting of the L-shaped electrode 44.

Referring next to FIGS. 6 and 7, an insulated, threaded insert 52 for use in mounting the L-shaped electrode 44 (FIGS. 4 and 5) is illustrated. The insulated, threaded insert 52 has a thinner diameter cylindrical top portion, and a thicker diameter cylindrical bottom portion. An aperture 54 extends through the top and bottom portions of the insulated, threaded insert 52. The length of the cylindrical top portion is approximately the same, or slightly less than, the wall thickness of a tube (not shown) in which the L-shaped electrode 44 will be mounted.

Referring now to FIGS. 8 and 9, the components of FIGS. 1 through 7 are shown mounted into a segment of tubing 56, one end of which has a radially outwardly extending flange 58 mounted thereon. The end of the tubing 56 having the flange 58 mounted thereon will be the outlet end of the tubing 56, with the other end of the tubing 56 being the inlet end of the tubing 56.

The top side of the tubing 56 has an aperture 60 located therein, with another aperture 62 being located diametrically opposite the aperture 60 in the bottom of the tubing 56. A third aperture 64 is also located in the top side of the tubing 56, and is spaced toward the inlet end of the tubing 56 from the aperture 60.

One of the curved electrode plates 40 is located inside the tubing 56 on the top side thereof, with the threaded stud 42 of the curved electrode plate 40 extending through the aperture 60. A nut 66 is attached to the threaded stud 42 of the curved electrode plate 40 located on the top inside wall of the tubing 56. The nut 66 secures (electrically and mechanically) both a wire 68 and the curved electrode plate 40 located on the top inside wall of the tubing 56.

Another one of the curved electrode plates 40 is located inside the tubing 56 on the bottom side thereof, with the threaded stud 42 of the curved electrode plate 40 extending through the aperture 62. A nut 70 is attached to the threaded stud 42 of the curved electrode plate 40 located on the bottom inside wall of the tubing 56. The nut 70 secures (electrically and mechanically) both a wire 72 and the curved electrode plate 40 located on the bottom inside wall of the tubing 56.

The insulated, threaded insert 52 is screwed onto the threaded shorter leg 50 of the L-shaped electrode 44 with the threaded shorter leg **50** being inserted into the thicker diameter cylindrical bottom portion of the insulated, threaded insert **52**. The L-shaped electrode **44** is inserted into the interior of the tubing **56**, and the threaded shorter leg **50** of the L-shaped electrode **44** is inserted through the aperture **64** in the tubing **56**.

A washer **74** is installed onto the threaded shorter leg **50** of the L-shaped electrode **44**. A nut **76** is installed onto the threaded shorter leg **50** of the L-shaped electrode **44**. The nut **76** is used to secure (electrically and mechanically) both a wire **78** and the L-shaped electrode **44** located inside the tubing **56**. Note that the curved electrode plates **40** are located opposite each other, and that the long leg **46** and the pointed tip **48** of the L-shaped electrode **44** are located between the curved electrode plates **40**. The pointed tip **48** of the L-shaped electrode **44** is directed toward the outlet end of the tubing **56**.

The flange **58** of the tubing **56** has disposed therein on the side facing away from the tubing **56** an annular recess **80** surrounding and spaced radially outwardly away from the aperture in the tubing **56**. The flange **58** has a plurality of longitudinally extending apertures **82** disposed uniformly around the outer perimeter of the flange **58** near the outer diameter thereof.

Referring now to FIGS. **10** through **14**, a first housing half **84** is illustrated which defines half of the housing of the particulate separator of the present invention. In the preferred embodiment contained herein, the housing of the particulate separator is made of plastic material in two halves which are fastened together adhesively. In fact, it could be made in any of a number of different ways which will occur to one skilled in the art upon reading this disclosure.

The first housing half **84** is made of a rectangular block of material machined or molded to form the features specified below. First, a particulate removal tube half (indicated generally at **86**) is located in and extends between the sides of the top half of the first housing half **84**. The particulate removal tube half **86** is semicircular in cross-section throughout, and varies uniformly from a larger diameter portion **88** on the left side of the first housing half **84** (as seen in FIG. **10**) to a smaller diameter portion **90** in the central portion of the first housing half **84**, and back to a larger diameter portion **92** on the right side of the first housing half **84** (as seen in FIG. **10**).

The larger diameter portion **88** of the particulate removal tube half **86** is the inlet portion of the particulate removal tube half **86**. The larger diameter portion **92** of the particulate removal tube half **86** is the outlet portion of the particulate removal tube half **86**. A plurality of threaded apertures **94** are disposed on the left end of the first housing half **84** in a semi-circular array around the larger diameter portion **88** of the particulate removal tube half **86**. Similarly, a plurality of threaded apertures **96** are disposed on the right end of the first housing half **84** in a semi-circular array around the larger diameter portion **92** of the particulate removal tube half **86**.

A passageway half **98** having a semi-circular cross-section extends vertically from the top of the smaller diameter portion **90** of the particulate removal tube half **86** to the top of the first housing half **84**.

Located in the bottom half of the first housing half **84** is a cylindrical recess **100** which will house half of the vortex generator. The cylindrical recess **100** in the preferred embodiment is just greater than three inches in diameter, and extends approximately one-third of the way through the first housing half **84**. Located in the center of and coaxial with the cylindrical recess **100** is a bearing receiving aperture **102**.

The bearing receiving aperture **102** has a diameter substantially less than that of the cylindrical recess **100**. The bearing receiving aperture **102** extends approximately two-thirds of the way through the first housing half **84**. Located in the center of and coaxial with the bearing receiving aperture **102** is a shaft aperture **104**, which extends through the first housing half **84**. The shaft aperture **104** has a diameter less than that of the bearing receiving aperture **102**.

An aperture **106** extends between the smaller diameter portion **90** of the particulate removal tube half **86** and the cylindrical recess **100**. This aperture **106** is half of the passage through which particulates will pass in exiting from the gas stream into the vortex generator.

A control gas inlet portion half **107** having a semi-circular cross-section extends vertically upwards from the bottom of the first housing half **84**. A control gas inlet passageway half **108** having a thin rectangular (slot-shaped) cross-section extends vertically from the left side of the cylindrical recess **100** (as seen in FIG. **10**) to the top of the control gas inlet portion half **107**, with which it is in fluid communication. The slot-shaped configuration of the control gas inlet passageway half **108** extends the entire depth of the cylindrical recess **100** (as best shown in FIGS. **12** and **14**), and in the preferred embodiment is approximately 0.010 inches wide.

A reference system to be used herein may now be defined with respect to the view of the cylindrical recess **100** shown in FIG. **10**. The top of the cylindrical recess **100** which communicates with the aperture **106** shall be referred to as **12** o'clock, and thus the control gas inlet passageway half **108** communicates with the cylindrical recess **100** at **9** o'clock.

The control gas inlet passageway half **108** is thus located tangentially with respect to the cylindrical recess **100**, and control gas emanating from the control gas inlet passageway half **108** will flow clockwise in the cylindrical recess **100** as viewed in FIG. ID A plurality of threaded apertures **109** are disposed on the bottom of the first housing half **84** in a semi-circular array around the control gas inlet passageway half **108**.

Mounted in the end of the cylindrical recess **100** surrounding and spaced radially outwardly from the bearing receiving aperture **102** are two split ring commutator segments **110** and **112**. The split ring commutator segment **110** extends from **11** o'clock or so to about three o'clock. The split ring commutator segment **112** extends from **4** o'clock or so to about **10** o'clock. The split ring commutator segment **110** is electrically connected to a wire **114**, which extends out of the first housing half **84** on the outside thereof. Similarly, the split ring commutator segment **112** is electrically connected to a wire **116**, which extends out of the first housing half **84** on the outside thereof.

Referring now to FIGS. **15** and **16**, a second housing half **124** is illustrated Which defines the other half of the housing of the particulate separator of the present invention. During the discussion of the second housing half **124**, reference may periodically be made to the first housing half **84** (FIGS. **10** through **14**), which is shown in greater detail. Differences in construction will be specifically noted; otherwise, the second housing half **124** is a mirror image of the first housing half **84**.

The second housing half **124** is also made of a rectangular block of material machined or molded to form the features specified below. First, a particulate removal tube half (indicated generally at **126**) is located in and extends between the sides of the top half of the second housing half **124**. The particulate removal tube half **126** is semicircular in cross-section throughout, and Varies uniformly from a larger diameter portion **128** on the right side of the second housing half **124** (as seen in FIG. **15**) to a smaller diameter portion **130** in the central portion of the second housing half **124**, and back to a larger diameter portion **132** on the left side of the second housing half **124** (as seen in FIG. **15**).

The particulate removal tube half **126** in the second housing half **124** and the particulate removal tube half **86** in the first housing half **84** together form a single particulate removal tube having a circular cross-section throughout.

The larger diameter portion **128** of the particulate removal tube half **126** is the inlet portion of the particulate removal tube half **126**. The larger diameter portion **132** of the particulate removal tube half **126** is the outlet portion of the particulate removal tube half **126**. A plurality of threaded apertures **94** are disposed on the right end of the second housing half **124** in a semi-circular array around the larger diameter portion **128** of the particulate removal tube half **126**. Similarly, a plurality of threaded apertures **96** are disposed on the left end of the second housing half **124** in a semi-circular array around the larger diameter portion **132** of the particulate removal tube half **126**.

A passageway half **138** having a semi-circular cross-section extends vertically from the top of the smaller diameter portion **130** of the particulate removal tube half **126** to the top of the second housing half **124**. The passageway half **138** in the second housing half **124** and the passageway half **98** in the first housing half **84** together form a single passageway having a circular cross-section.

Located in the bottom half of the first housing half **124** is a cylindrical recess **140** which will house the other half of the vortex generator. The cylindrical recess **140** in the preferred embodiment is just greater than three inches in diameter, and extends approximately one-third of the way through the second housing half **124**. The cylindrical recess **140** in the second housing half **124** and the cylindrical recess **100** in the first housing half **84** together form a single cylindrical recess.

Located in the center of and coaxial with the cylindrical recess **140** is a bearing receiving aperture **142**. The bearing receiving aperture **142** has a diameter substantially less than that of the cylindrical recess **140**. In addition, the bearing receiving aperture **142** has a diameter less than the diameter of the bearing receiving aperture **102** in the first housing half **84**. The bearing receiving aperture **142** extends approximately two-thirds of the way through the second housing half **124**.

Located in the center of and coaxial with the bearing receiving aperture **142** is a shaft aperture **144**, Which extends through the second housing half **124**. The shaft aperture **144** has a diameter less than that of the bearing receiving aperture **142**. In addition, the shaft aperture **144** has a diameter less than the diameter of the shaft aperture **104** in the first housing half **84**.

An aperture **146** extends between the smaller diameter portion **130** of the particulate removal tube half **126** and the cylindrical recess **140**. This aperture **146** is half of the passage through which particulates will pass in exiting from the gas stream into the vortex generator. The entire passage consists of the aperture **146** in the second housing half **124** together with the aperture **106** in the first housing half **84**.

A control gas inlet portion half **147** having a semi-circular cross-section extends vertically upwards from the bottom of second housing half **124**. A control gas inlet passageway half **148** having a thin rectangular (slot-shaped) cross-section extends vertically from the right side of the cylindrical recess **140** (as seen in FIG. to the top of the control gas inlet portion half **147**, with which it is in fluid communication. The slot-shaped configuration of the control gas inlet passageway half **148** extends the entire depth of the cylindrical recess **140**, and in the preferred embodiment is approximately 0.010 inches wide.

The control gas inlet portion half **147** in the second housing half **124** and the control gas inlet portion half **107** in the first housing half **84** together form the control gas inlet portion. The control gas inlet passageway half **148** in the second housing half **124** and the control gas inlet passageway half **108** in the first housing half **84** together form the control gas inlet passageway, which is in fluid communication with the control gas inlet portion.

The control gas inlet passageway half **148** is thus located tangentially with respect to the cylindrical recess **140**, and control gas emanating from the control gas inlet passageway half **148** will flow counterclockwise in the cylindrical recess **140** as viewed in FIG. **15**. A plurality of threaded apertures **109** are disposed on the bottom of the second housing half **124** in a semi-circular array around the control gas inlet passageway half **148**.

Mounted in the end of the cylindrical recess **140** surrounding and spaced radially outwardly from the bearing receiving aperture **142** are two split ring commutator segments **150** and **152**. The split ring commutator segments **150** and **152** have a radius the same as the radius of the split ring commutator segments **110** and **112** in the first housing half **84**. The split ring commutator segments **150** and **152** are mirror images of the split ring commutator segments **110** and **112** in the first housing half **84**. The split ring commutator segment **150** is electrically connected to a wire **154**, which extends out of the second housing half **124** on the outside thereof. Similarly, the split ring commutator segment **152** is electrically connected to a wire **156**, which extends out of the second housing half **124** on the outside thereof.

Referring now to FIGS. **17** and **18**, a curved electrode plate **158** is illustrated Which is contoured to fit into the top of the smaller diameter portions **90** and **130** of the particulate removal tubes **86** and **126**, respectively. When installed in this location, the curved electrode plate **158** is located opposite the apertures **106** and **146**. The curved electrode plate **158** has a long stud **160** mounted in a central position on the convex side thereof, with the long stud **160** being orthogonal to a plane tangent to the convex side of the curved electrode plate **158**. The threaded stud **160** may be soldered to the curved electrode plate **158**. The curved electrode plate **158** and the threaded stud **160** are both made of conductive material. The end of the long stud **160** not attached to the curved electrode plate **158** is threaded.

Referring now to FIGS. **19** and **20**, a bearing and seal **162** for mounting in the bearing receiving aperture **102** in the first housing half **84** (FIG. **10**) is illustrated. The outer diameter of the bearing and seal **162** is sized for an interference fit in the bearing receiving aperture **102**.

Referring now to FIGS. **21** and **22**, a bearing and seal **164** for mounting in the bearing receiving aperture **142** in the second housing half **124** (FIG. **15**) is illustrated. The outer diameter of the bearing and seal **164** is sized for an interference fit in the bearing receiving aperture **142**.

Referring next to FIGS. **23** and **24**, a first rotor **166** consisting of a disk **168** mounted on a hollow shaft **170** is illustrated. The disk **168** is approximately three inches in diameter in the preferred embodiment, and is made of a dielectric material such as plastic. The hollow shaft **170** is attached to the disk **168** at the center thereof, and the aperture through the hollow shaft **170** extends through to the front of the disk **168**.

The diameter of the hollow shaft **170** is sized to fit in the inner diameter of the bearing and seal **162** (FIGS. **19** and **20**) to support the disk **168** and the hollow shaft **170** for rotation. Thus, the diameter of the disk **168** is just less than the diameter of the cylindrical recess **100** (FIG. **10**).

Mounted in recessed, spaced-apart fashion On the front side of the disk **168** are a plurality of pie-shaped conductive segments **172**. In the preferred embodiment shown there are eight conductive segments **172**. There could be from approximately four to twenty conductive segments **172** on the disk **168**. The conductive segments **172** are preferably made of copper.

Located on the back side of the disk **168** are eight contacts **174** which are each electrically connected to one of the eight conductive segments **172**. The radius at which the contacts **174** are mounted is equal to the radius at which the split ring commutator segments **110** and **112** (FIG. **10**) are mounted in the first housing half **84**. Thus, as the first rotor **166** rotates, the contacts **174** will move in contact With the split ring commutator segments **110** and **112**, continuously connecting the conductive segments **172** to one of the wires **114** and **116** (FIG. **10**).

Located on the hollow shaft **170** is a keyway **175**, which will be used to mount a gear (not shown) for driving the first rotor **166**.

Referring next to FIGS. **25** and **26**, a second rotor **176** consisting of a disk **178** mounted on a solid shaft **180** is illustrated. The disk **178** is also approximately three inches in diameter in the preferred embodiment, and is made of a dielectric material such as plastic. The shaft **180** is attached to the disk **178** at the center thereof.

The diameter of the shaft **180** is sized to fit in the inner diameter of the bearing and seal **164** (FIGS. **21** and **22**) to support the disk **178 1** and the shaft **180** for rotation. Thus, the diameter of the disk **178** is just less than the diameter of the cylindrical recess **140** (FIG. **15**).

Mounted in recessed, spaced-apart fashion on the front side of the disk **178** are a plurality of pie-shaped conductive segments **182**. In the preferred embodiment shown there are eight conductive segments **182**. The conductive segments **182** are preferably made of copper.

Located on the back side of the disk **178** are eight contacts **184** which are each electrically connected to one of the eight conductive segments **182**. The radius at which the contacts **184** are mounted is equal to the radius at which the split ring commutator segments **150** and **152** (FIG. **15**) are mounted in the second housing half **124**. Thus, as the second rotor **176** rotates, the contacts **184** will move in contact with the split ring commutator segments **150** and **152**, continuously connecting the conductive segments **182** to one of the wires **154** and **156** (FIG. **15**).

Located on the shaft **180** is a keyway **185**, which will be used to mount a gear (not shown) for driving the second rotor **176**.

Referring next to FIG. **27**, an L-shaped connector tube **190** is illustrated. The L-shaped connector tube **190** has at One end thereof a seal **192** therein for sealingly, rotatably receiving the end of the hollow shaft **170** of the first rotor **166** (FIGS. **23** and **24**). The other end of the L-shaped connector tube **191** has a flange **194** mounted thereon. The flange **194** has a plurality of longitudinally extending threaded apertures **196** disposed uniformly around the outer perimeter of the flange **194** near the outer diameter thereof.

Referring now to FIGS. **28** through **30**, a pressure letdown device **200** having a body **202** open at the ends thereof is illustrated. A flange **204** is mounted on the body **202** at the inlet end of the pressure letdown device **200**. The flange **204** has disposed therein on the side facing away from the body **202** of the pressure letdown device **200** an annular recess **206** surrounding and spaced radially outwardly away from the aperture in the flange **204**. The flange **204** has a plurality of longitudinally extending apertures **208** disposed uniformly around the outer perimeter of the flange **204** near the outer diameter thereof.

Disposed inside the body **202** of the pressure letdown device **200** are a plurality of plates **210**, **212**, **214**, **216**, **218**, and **220** each having an aperture **222**, **224**, **226**, **228**, **230**, and **232**, respectively, therein. The plates **210**, **212**, **214**, **216**, **218**, and **220** and apertures **222**, **226**, **228**, **230**, and **232** function to drop the pressure from high pressure at the inlet of the pressure letdown device **200** on the left to atmospheric pressure at the outlet on the right.

The apertures **222**, **224**, **226**, **228**, **230**, and **232** are in effect orifices which produce pressure drops. The apertures **222**, **224**, **226**, **228**, **230**, and **232** continually increase in size to maintain velocity through the apertures, thereby minimizing erosion. In addition, the apertures **222**, **224**, **226**, **228**, **230**, and **232** are offset or staggered from each other as shown to allow the plates **210**, **212**, **214**, **216**, **218**, and **220** to be closer to each other (smaller plenums). The outlet side of the body **202** has a segment of the tubing **234** mounted thereon.

Referring next to FIGS. **31** and **32**, a control gas supply tube **236** is illustrated. The control gas supply tube **236** has a flange **238** mounted thereon at the outlet end of the control gas supply tube **236**. The flange **238** has disposed therein on the side facing away from the control gas supply tube **236** an annular recess **240** surrounding and spaced radially outwardly away from the aperture in the flange **238**. The flange **238** has a plurality of longitudinally extending apertures **242** disposed uniformly around the outer perimeter of the flange **238** near the outer diameter thereof.

Referring finally to FIGS. **33** through **35**, the assembly and operation of the particulate separator of the present invention may now be discussed. As shown in FIG. **34**, the first rotor **166** (FIGS. **23** and **24**) is mounted in the first housing half **84** (FIG. **10**), and the second rotor **176** (FIGS. **25** and **26**) is mounted in the second housing half **124** (FIG. **15**).

The curved electrode plate **158** is mounted at the top of the smaller diameter portions **90** and **130** of the particulate removal tubes **86** and **126**, respectively. When installed in this location, the curved electrode plate **158** is located opposite the apertures **106** and **146**. The long stud **160** extends through the passageway created by the passageway halves **98** and **138**.

At this point the first housing half **84** and the second housing half **124** are mounted together, preferably using adhesive mounting means. In other embodiments, multiple housing parts may be mounted together with gaskets used instead of an adhesive to provide a seal between the respective housing parts. Following assembly of the housing, the curved electrode plate **158** is secured in place by placing a nut **250** on the threaded end of the long stud **160**. The nut **250** secures (electrically and mechanically) both a wire **252** and the curved electrode plate **158**.

The apparatus used to charge the particulates (FIGS. **8** and **9**) is installed onto the first housing half **84** and the second housing half **124**. An O-ring **254** is installed in the annular recess **80** on the flange **58**. A plurality of bolts **256** are placed through the apertures **82** in the flange **58** and are screwed into the threaded apertures **94** in the first housing half **84** (FIG. **10**) and the second housing half **124** (FIG. **15**). The end of the tubing **56** opposite the flange **58** is attached to a reactor **258** (FIG. **33**).

One of the pressure letdown devices **200** is installed onto the first housing half **84** and the second housing half **124**. An O-ring **260** is installed in the annular recess **206** on the flange **204**. A plurality of bolts **262** are placed through the apertures **208** in the flange **204** and are screwed into the threaded apertures **96** in the first housing half **84** (FIG. **10**) and the second housing half **124** (FIG. **15**).

The L-shaped connector tube **190** (FIG. **27**) is connected With the seal **192** installed on the end of the hollow shaft **170** of the first rotor **166** (FIGS. **23** and **24**). A second one of the pressure letdown devices **200** is installed onto the L-shaped connector tube **190**. An O-ring **260** (not shown) is installed in the annular recess **206** on the flange **204**. A plurality of bolts **262** are placed through the apertures **208** in the flange **204** and are screwed into the threaded apertures **196** in the flange **194** of the L-shaped connector tube **190**.

The control gas supply tube **236** is connected to communicate with the control gas inlet portion half **107** and the control gas inlet portion half **147**, and thus with the control gas inlet passageway half **108** and the control gas inlet passageway half **148**. An O-ring **261** is installed in the annular recess **240** on the flange **238**. A plurality of bolts **263** are placed through the apertures **242** in the flange **238** and are screwed into the threaded apertures **109** in the bottom of the first housing half **84** and the second housing half **124**.

Referring now specifically to FIG. **34**, the drive mechanism for the first rotor **166** and the second rotor **176** may be described. A gear **264** is installed onto the hollow shaft **170** of the first rotor **166** using a key **266** located in the keyway **175** (FIG. **24**). Similarly, a gear **268** is installed onto the hollow shaft **180** of the second rotor **176** using a key **270** located in the keyway **185** (FIG. **26**).

A motor **272** located below the first housing half **84** and the second housing half **124** drives a shaft **274**. The shaft **274** has a gear **276** located at one end thereof, and a gear **278** located at the other end thereof. The motor **272** thus drives the gears **276** and **278**. The gear **276** drives the gear **264** using a chain **280**, while the gear **278** drives the gear **268** using a chain **282**. The motor **272** is operated by a DC power source **284** through wires **286**.

The motor **272** thus drives the disks **168** and **178** on the first and second rotors **166** and **176**, respectively, to rotate. Referring now to FIG. **35**, the disk **168** on the first rotor **166** is driven in a clockwise direction. The disk **178** on the second rotor **176** would be driven in the same direction, and at the same speed as the disk **168** on the first rotor **166**. In the preferred embodiment, the disks **168** and **178** are rotated at approximately 15 RPM. The speed of rotation, as well as the size of the disks **168** and **178**, is dependent on the composition of the gas stream and the particulates contained therein.

A brief description of the operation of the device may now be given, again with reference to FIGS. **33** through **35**. The motor **272** is used to rotate the disks **168** and **178** in the manner described above. Compressed air is supplied to the control gas supply tube **236**, which directs the compressed air through the control gas inlet portion half **107** and the control gas inlet portion half **147** into the control gas inlet passageway half **108** and the control gas inlet passageway half **148**, and thus into the cylindrical recess **100** and the cylindrical recess **140**.

This generates a vortex, since the control gas will exit through the aperture in the hollow shaft **170** of the first rotor **166**, and from there into the L-shaped connector tube **190** and the second pressure letdown device **200**. The pressure of the control gas is of course dependent on the pressure of the gas stream exiting from the reactor **258**. However, the control gas does act to form a vortex in the cylindrical recess **100** and the cylindrical recess **140**.

A high voltage power supply **288** produces the high voltage necessary to perform the charging of the particulates and the electrostatic operation of the device. For example, a voltage of 1000 Volts from the high voltage power supply **288** may be utilized by the system of the present invention. The positive output of the high voltage power supply **288** is connected to the wire **78**, the wire **252**, the wire **114**, and the wire **154**. The negative output of the high voltage power supply **288** is connected to the wire **68**, the wire **72**, the wire **116**, and the wire **156**.

As particles pass through the tubing **56**, they are charged with a positive charge. As they pass into the particulate removal tube halves **86** and **126**, they are Channeled to the smaller diameter portions **90** and **130** of the particulate removal tube halves **86** and **126**. At this point, the positive charge on the curved electrode plate **158** forces the positively charged particulates through the apertures **106** and **146** (which effectively form an airblock) into the vortex chamber.

The conductive segments **172** and **182** on the disks **168** and **178** adjacent the apertures **106** and **146** are negatively charged, and thus attract the positively charged particulates. As the conductive segments **172** and **182** on the disks **168** and **178** rotate to approximately four o'clock, they become positively charged and repel the positively charged particulates. At this point, the vortex airflow takes the particulates into the aperture in the hollow shaft **170** of the first rotor **166** and out of the device. Thus, the device operates to separate particulates from the gas stream from the reactor vessel.

It may therefore be appreciated from the above detailed description of the preferred embodiment of the present invention that it teaches a device which operates to remove substantially all of the particulates contained in the gas stream emanating from a reactor vessel. The particulate separator of the present invention is operable on a continuous, high pressure gas stream which includes particulates to process the gas stream to remove the particulates as efficiently as is possible. The particulate separator will operate to remove the small particulates typically contained in a reactor vessel gas stream, despite the fact that they range from approximately two to five microns, and thereby have small settling rates.

The particulate removal system of the present invention operates in a manner not requiring a scrubbing fluid, therefore not further exacerbating the problem of substance disposal. In addition, the present invention does not involve the use of a filter medium and its attendant problems of clogging or requiring periodic maintenance or changing. The present invention also effectively separates the gas in the gas stream from particulates contained therein while using as little gas in the particulate waste stream as is possible.

In addition, the particulate separator of the present invention is relatively compact and inexpensive, both to construct, and also to operate and maintain. The particulate separator of the present invention enables the conversion of the high pressure gas stream containing particulates into a low pressure outlet flow of gas at a first output point, and a low pressure outflow of particulates and a small amount of gas at a second output point. Finally, all of the aforesaid advantages and objectives are achieved without incurring any substantial relative disadvantage.

Although an exemplary embodiment of the present invention has been shown and described, it will be apparent to those having ordinary skill in the art that a number of changes, modifications, or alterations to the invention as described herein may be made, none of which depart from the spirit of the present invention. All such changes, modifications, and alterations should therefore be seen as within the scope of the present invention.

What is claimed is:

1. A method of separating particulates contained in a gas stream emanating from a source, comprising:
   - defining a flow path through which the gas stream flows, said flow path having an inlet portion and an outlet portion with a central portion disposed between said inlet and outlet portions;
   - charging particulates in the gas stream entering said inlet portion of said flow path;
   - generating a vortex flow with a vortex generator disposed outside said flow path adjacent said central portion of said flow path, said vortex flow leaving said vortex generator through a vortex outlet;
   - inducing particulates from the gas stream in said flow path to pass from said central portion of said flow path through a passageway located in said central portion of said flow path into said vortex generator; and
   - diverting particulates entering said vortex generator into said vortex flow, and inwardly into said vortex outlet, whereby the particulates are exhausted from said vortex generator through said vortex outlet.

2. A device for separating particulates contained in a gas stream emanating from a source, comprising:
   - means for defining a flow path through which the gas stream flows, said flow path having an inlet portion and an outlet portion with a central portion disposed between said inlet and outlet portions;
   - means for charging particulates in the gas stream entering said inlet portion of said flow path;
   - a vortex generator disposed outside said flow path adjacent said central portion of said flow path, said vortex generator generating a vortex flow which leaves said vortex generator through a vortex outlet;
   - a passageway between said central portion of said flow path and said vortex generator;
   - means, disposed in said central portion of said flow path, for inducing particulates from the gas stream in said flow path to pass through said passageway into said vortex generator; and
   - means, located in said vortex generator, for diverting particulates entering said vortex generator into said vortex flow, whereby the particulates are exhausted from said vortex generator through said vortex outlet.

3. A device as defined in claim 2, additionally comprising:
   - pressure letdown means for dropping the pressure of the gas stream exiting said outlet portion of said flow path to atmospheric pressure.

4. A device as defined in claim 2, additionally comprising:
   - pressure letdown means for dropping the pressure of the vortex flow carrying particulates exiting said vortex outlet to atmospheric pressure.

5. A device as defined in claim 2, wherein said means for defining a flow path comprises:
   - a particulate removal tube having said inlet portion of said flow path at a first end thereof and said outlet portion of said flow path at a second end thereof, said central portion of said flow path being located intermediate said first and second ends of said particulate removal tube.

6. A device as defined in claim 5, wherein said particulate removal tube is made of a dielectric material.

7. A device as defined in claim 5, wherein said particulate removal tube is substantially circular in cross-section throughout the length thereof.

8. A device as defined in claim 5, wherein said particulate removal tube varies uniformly from a larger diameter portion at said first end thereof to a smaller diameter portion intermediate said first and second ends in the central portion of said flow path, and back to a larger diameter portion at said second end thereof.

9. A device as defined in claim 5, wherein said means for charging particulates comprises:
   - a segment of hollow tubing interposed between the source of the gas stream and particulates and said inlet portion of said flow path;
   - first electrode means disposed on the inner surface of said segment of hollow tubing; and
   - second electrode means located in the interior of said segment of hollow tubing at a central location therein, a high voltage being placed across said first and second electrode means.

10. A device as defined in claim 9, wherein said first electrode means comprises:
   - a first curved plate mounted on the inner surface of said segment of hollow tubing on one side thereof; and
   - a second curved plate mounted on the inner surface of said segment of hollow tubing on a side thereof

opposite said first curved plate; and wherein said second electrode means comprises:

an L-shaped electrode having a leg disposed substantially longitudinally in the interior of said segment of hollow tubing intermediate said first and second curved plates.

11. A device as defined in claim **2**, wherein said means for inducing particulates to pass through said passageway comprises:

electrostatic means for diverting particulates which have been charged by said means for charging particulates through said passageway and into said vortex generator.

12. A device as defined in claim **11**, wherein said means for inducing particulates to pass through said passageway comprises:

a charged plate located in said central portion of said flow path on one side of said flow path, said passageway being located on an opposite side of said flow path, said charged plate having a charge which repels particulates which have been charged by said means for charging particulates.

13. A device as defined in claim **2**, wherein said vortex generator comprises:

a cylindrical chamber having a first end and a second end, said passageway communicating with said cylindrical chamber in the side thereof at a first location intermediate said first and second ends of said cylindrical chamber; and

a control gas inlet through which control gas is supplied under pressure to said cylindrical chamber, said control gas inlet being located in the side of said cylindrical chamber at a second location intermediate said first and second ends of said cylindrical chamber, said control gas entering said cylindrical chamber through said control gas inlet in essentially tangential fashion to create said vortex flow in a first rotational direction within said cylindrical chamber.

14. A device as defined in claim **13**, wherein said vortex outlet is located in said cylindrical chamber at a location centered within said cylindrical chamber.

15. A device as defined in claim **13**, wherein said means for diverting particulates into said vortex flow comprises:

electrostatic means for diverting particulates which have been charged by said means for charging particulates and which are entering said vortex generator into said vortex flow.

16. A device as defined in claim **15**, wherein said means for diverting particulates into said vortex flow comprises:

a first rotor comprising a first disk mounted on a hollow shaft at a first end of said hollow shaft, said first disk being mounted for rotation in said cylindrical chamber adjacent to and parallel to said first end of said cylindrical chamber, a second end of said hollow shaft extending out of said cylindrical chamber;

a first plurality of pie-shaped conductive segments disposed on the side of said first disk facing said second end of said cylindrical chamber; and

first means for supplying a charge to said first plurality of pie-shaped conductive segments disposed on said side of said first disk facing said second end of said cylindrical chamber in a manner diverting the particulates into said vortex flow.

17. A device as defined in claim **16**, wherein said hollow shaft is open at said first end thereof in the center of said first disk to provide said vortex outlet, said vortex flow thus leaving said vortex generator through said second end of said hollow shaft.

18. A device as defined in claim **16**, wherein said means for diverting particulates into said vortex flow additionally comprises:

a second rotor comprising a second disk mounted on a solid shaft at a first end of said solid shaft, said second disk being mounted for rotation in said cylindrical chamber adjacent to and parallel to said second end of said cylindrical chamber, a second end of said solid shaft extending out of said cylindrical chamber;

a second plurality of pie-shaped conductive segments disposed on the side of said second disk facing said first end of said cylindrical chamber; and

second means for supplying a charge to said second plurality of pie-shaped conductive segments disposed on said side of said second disk facing said first end of said cylindrical chamber in a manner diverting the particulates into said vortex flow. for supplying a charge to said second plurality of pie-shaped conductive segments are arranged and configured to charge said first and second plurality of pie-shaped segments to a charge repelling particulates which have been charged by said means for charging particulates to allow the particulates to be exhausted from said vortex generator through said vortex outlet.

19. A device as defined in claim **18**, wherein there are between four and twenty of said first plurality of pie-shaped conductive segments disposed on the side of said first disk, and between four and twenty of said second plurality of pie-shaped conductive segments disposed on the side of said second disk.

20. A device as defined in claim **18**, wherein there are approximately eight of said first plurality of pie-shaped conductive segments disposed on the side of said first disk, and approximately eight of said second plurality of pie-shaped conductive segments disposed on the side of said second disk.

21. A device as defined in claim **18**, wherein said first plurality of pie-shaped conductive segments disposed on the side of said first disk are recessed into the surface of said first disk, and wherein said second plurality of pie-shaped conductive segments disposed on the side of said second disk are recessed into the side of said second disk.

22. A device as defined in claim **18**, wherein said first and second disks are each approximately three inches in diameter.

23. A device as defined in claim **18**, additionally comprising:

means for rotating said first and second disks in the same direction and at the same angular velocity.

24. A device as defined in claim **23**, wherein said first and second disks are rotated in said first rotational direction within said cylindrical chamber.

25. A device as defined in claim **23**, wherein said first and second disks are rotated at a speed of approximately 15 RPM.

26. A device as defined in claim **23**, wherein said first means for supplying a charge to said first plurality of pie-shaped conductive segments and said second means for supplying a charge to said second plurality of pie-shaped conductive segments are arranged and configured to charge said first and second plurality of pie-shaped segments to a charge attracting particulates which have been charged by said means for charging particulates when said first and second plurality of pie-shaped segments are located adjacent said passageway to move the particulates into said vortex flow, at which point said first means for supplying a charge to said first plurality of pie-shaped conductive segments and said second means for supplying a charge to said second plurality of pie-shaped conductive segments are arranged and configured to charge said first and second plurality of pie-shaped segments to a charge repelling particulates which have been charged by said means for charging particulates to allow the particulates to be exhausted from said vortex generator through said vortex outlet.

27. A device for separating particulates contained in a gas stream emanating from a source, comprising:

means for defining a flow path through which the gas stream flows, said flow path having an inlet portion and an outlet portion with a central portion disposed between said inlet and outlet portions;

first electrostatic means for charging particulates in the gas stream entering said inlet portion of said flow path;

a vortex generator means for directing a gas stream and particulates inwardly which is disposed in a cylindrical chamber located outside said flow path adjacent said central portion of said flow path, said vortex generator generating a vortex flow in said cylindrical chamber which leaves said cylindrical chamber through a vortex outlet;

a passageway between said central portion of said flow path and said vortex generator;

second electrostatic means, disposed in said central portion of said flow path opposite said passageway, for repelling particulates form the gas stream in said flow path through said passageway into said vortex generator; and

third electrostatic means, located in said vortex generator, for diverting particulates entering said vortex generator into said vortex flow, whereby the particulates are exhausted from said vortex generator through said vortex outlet.

28. A device for separating particulates contained in a gas stream, comprising:

means for defining a flow path through which the gas stream flows:

a vortex generator disposed outside said flow path, said vortex generator generating a vortex flow with a second gas stream which leaves said vortex generator through a vortex outlet;

means for inducing particulates form the gas stream in said flow path to pass through a passageway into said vortex generator; and

means for diverting particulates entering said vortex generator inwardly into said vortex flow and through said vortex outlet.

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